

# A Very Large Glitch in PSR J1806–2125

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## ABSTRACT

PSR J1806–2125 is a pulsar discovered in the Parkes multibeam pulsar survey with a rotational period of 0.4 s and a characteristic age of 65 kyr. Between MJDs 51462 and 51894 this pulsar underwent an increase in rotational frequency of  $\Delta\nu/\nu \approx 16 \times 10^{-6}$ . The magnitude of this glitch is  $\sim 2.5$  times greater than any previously observed in any pulsar and 16 times greater than the mean glitch size. This letter gives the parameters of the glitch and compares its properties to previously observed events. The existence of such large and rare glitches offers new hope for attempts to observe thermal X-ray emission from the internal heat released following a glitch, and suggests that pulsars which previously have not been observed to glitch may do so on long timescales.

**Key words:** pulsars: individual (PSR J1806–2125) — neutron stars: glitches

## 1 INTRODUCTION

The spin-down of pulsars is usually remarkably steady and predictable. However, timing observations of young pulsars have revealed rotational irregularities such as timing noise, a noise-like fluctuation in rotation rate, and glitches which manifest themselves in a sudden spin-up of the pulsars (e.g. Lyne, Shemar & Graham-Smith 2000). Typical increases in rotational frequency during a glitch are of the order of  $\Delta\nu/\nu = 10^{-8}$  to  $10^{-6}$  which is followed by a relaxation process during which the pulsar usually returns to its pre-glitch spin-down rate. The time scales for relaxation vary from hours to years, depending on pulsar and glitch event.

Observing glitches and their relaxation processes provides a unique method for studying the interior of neutron stars: glitches are thought to be caused by a sudden transfer of angular momentum from a faster-rotating component of the superfluid interior to the solid crust of the pulsar. Hence, monitoring pulsars to detect glitches and to measure their subsequent relaxation provides a kind of rotational seismology to probe neutron star interiors (e.g. Pines 1991; Lyne 1992).

In this Letter we present the largest glitch event ever

observed, with a fractional frequency increase almost 2.5 times larger than the previously known largest glitch (Wang et al. 2000) and 16 times greater than the mean glitch size. This glitch was observed in PSR J1806–2125, a pulsar which was discovered in the Parkes multibeam survey (Manchester et al. 2001). This survey has discovered numerous young pulsars, which are subsequently monitored using the Parkes 64-m or the Jodrell Bank 76-m radio telescopes. The discovery of PSR J1806–2125 is reported in Morris et al. (2002). The pulsar has a rotational period of  $P = 0.4$  s and a characteristic age of 65 kyr.

## 2 OBSERVATIONS

Following its discovery, PSR J1806–2125 was observed 37 times using the 76-m Lovell radio telescope at Jodrell Bank Observatory between January 1998 and October 1999 (MJDs 50820 and 51462), and again from January 2002 (MJD 52298). The observing system is described in Morris et al. (2002). In brief, the two hands of circular polarisation at a frequency near 1400 MHz are fed through a multichannel filterbank and digitised. The data are dedispersed and folded on-line according to the pulsar’s dispersion measure

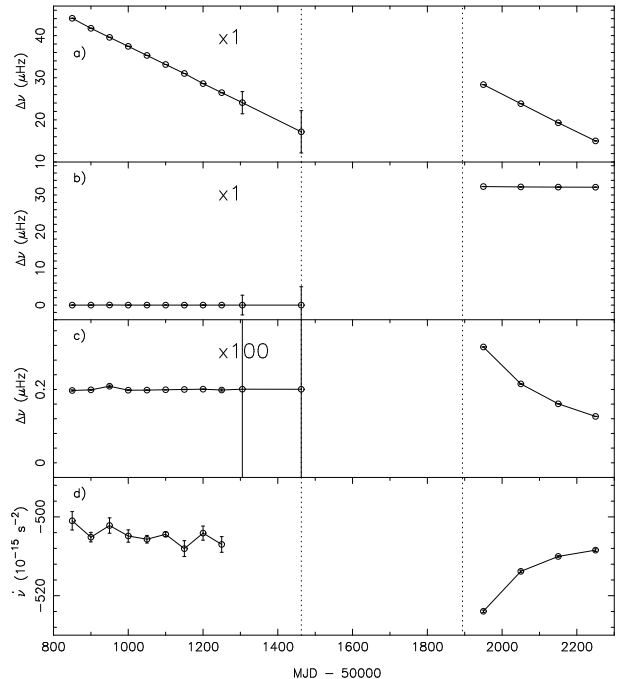
**Table 1.** Observed and derived parameters for PSR J1806–2125. The characteristic age is calculated as  $P/(2\dot{P})$ , the surface magnetic dipole field strength as  $3.2 \times 10^{19} (P\dot{P})^{1/2}$  Gauss and the rate of loss of rotational energy as  $4\pi^2 I \dot{P} P^{-3}$  where a neutron star with moment of inertia  $I = 10^{45} \text{ g cm}^2$  is assumed.

|   |   |
|---|---|
| Right ascension (J2000)   | $18^{\text{h}}06^{\text{m}}19.^{\text{s}}59(8)$ |
| Declination (J2000)   | $-21^{\circ}25'40''(24)$                        |
| Period (s)  | $0.48178844377(6)$                              |
| Period derivative ( $10^{-15}$ )                                | $117.295(14)$                                   |
| Frequency, $\nu$ (Hz)   | $2.075598051(2)$                                |
| Frequency derivative, $\dot{\nu}$ ( $10^{-15} \text{ s}^{-2}$ ) | $-505.32(6)$                                    |
| Period/frequency epoch (MJD)                                    | 51062.8   |
| Dispersion measure ( $\text{cm}^{-3} \text{ pc}$ )              | $750(3)$  |
| rms timing residual (ms)  | 3.5   |
| Epoch range (MJD)   | 50820–51305                                     |
| Flux Density at 1400 MHz (mJy)                                  | $1.1(2)$  |
| Characteristic age (kyr)  | 65  |
| Surface magnetic field ( $10^{12} \text{ G}$ )                  | 7.8   |
| Rate of loss of rotational energy ( $\text{erg s}^{-1}$ )       | $4.1 \times 10^{34}$                            |

and topocentric period. The folded pulse profiles for each polarisation are subsequently combined to produce the total intensity. Pulse times-of-arrival (TOAs) are determined by cross-correlating the profile with a template of high signal-to-noise ratio. During the upgrade period of the Lovell telescope, timing observations are continuing using the central beam of the 13-beam system installed on the 64-m Parkes radio telescope (Manchester et al. 2001). Between December 2000 and January 2002 (MJDs 51894 and 52257), the pulsar was observed 14 times with a typical integration time of 240 s.

### 3 RESULTS

The rotational, positional and derived parameters for PSR J1806–2125 are given in Table 1. These parameters are obtained by model-fitting the Jodrell Bank pulse TOAs using TEMPO<sup>1</sup>. All uncertainties are twice the standard TEMPO values. The rotational frequency of the pulsar increased between October 1999 and December 2000, indicating that a glitch had occurred. The nature of the event is summarised in Figure 1. The rotational frequencies versus time are plotted in Figure 1a. It is clear that sometime during the 430 day gap between observations, approximately 700 days of normal spin-down were reversed. Assuming, as argued later, that this occurred in a single event, the step change in rotation rate was  $\Delta\nu/\nu \approx 16 \times 10^{-6}$ . The frequencies for the final two pre-glitch Jodrell Bank observations were obtained by determining the shift in the pulse profile across the integration time of  $\sim 20$  minutes. All other frequencies were obtained from a least-squares fit of a timing model to 4–8 adjacent TOAs, keeping positional parameters and the frequency derivative fixed with the epoch set to the midpoint of the TOAs. The effect of subtracting the pre-glitch

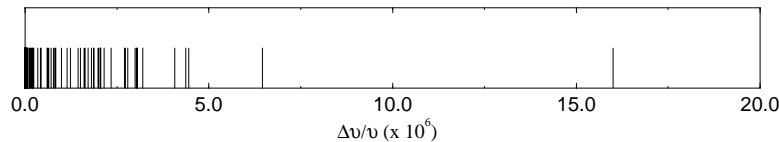


**Figure 1.** a) The rotational frequency,  $\nu$ , offset by 2.075565 Hz, between MJDs 50850 and 52250, b) the same after subtracting the ephemeris in Table 1, c) to observe structure in the post-fit data an arbitrary offset has been added and the scale increased by a factor of 100 and d) the frequency derivative,  $\dot{\nu}$ . To obtain these plots, fits were made to pulse arrival times to obtain frequency and frequency derivatives assuming the position and dispersion measure given by the ephemeris in Table 1. The dashed lines indicate the last Jodrell Bank observation and first Parkes observation before and after the glitch. In most cases the uncertainties are smaller than the size of the symbol.

rotational frequency and frequency derivative, determined from the Jodrell Bank data, is shown in Figure 1b. To view structure in the post-glitch residuals, an offset is subtracted from the post-fit data and the scale expanded by a factor of 100 (Figure 1c). The post-glitch rotational frequency decays with time over a few hundred days. The changing frequency derivative is shown in Figure 1d. The last observation prior to the glitch was obtained at Jodrell Bank on MJD 51462 and the first observation after the glitch was obtained at Parkes on MJD 51894 (indicated by dotted lines in Figure 1). Unfortunately, the large interval between the Jodrell Bank and Parkes observations prevents extrapolation of the pre- and post-glitch pulse ephemerides without pulse period ambiguities. We can therefore only deduce that the glitch occurred sometime between the two dates.

Table 2 gives the pre-glitch value of the frequency,  $\nu$ , and its first and second derivatives extrapolated to the epoch of the first observation after the glitch (MJD 51894). This table also contains the analogous post-glitch parameters given for the same epoch and the instantaneous changes at the glitch. For the pre-glitch data,  $\ddot{\nu}$  reflects timing noise, however in the post-glitch data,  $\ddot{\nu}$  describes both the timing noise and the recovery from the glitch. No other glitch events are visible in the data limiting the magnitudes of any glitches to less than  $\Delta\nu/\nu \approx 10^{-9}$ . In some cases, glitches may be confused with timing noise particularly when there

<sup>1</sup> See <http://pulsar.princeton.edu/tempo>.



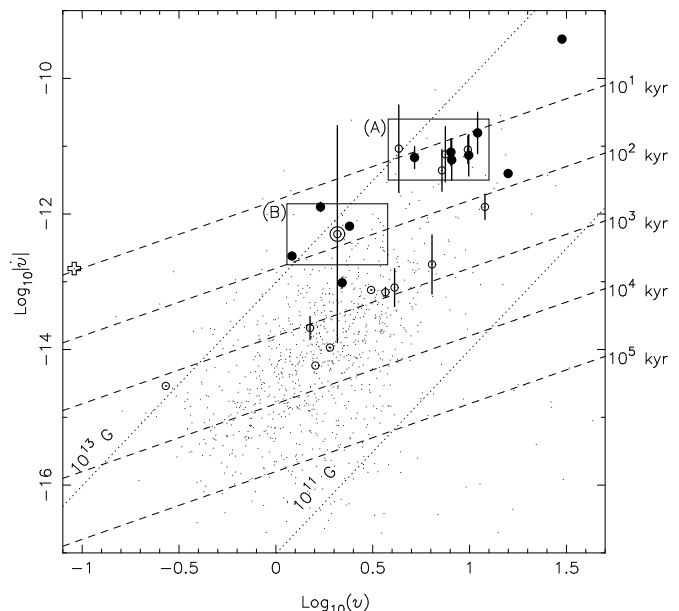
**Figure 2.** Fractional change in rotational frequency ( $\Delta\nu/\nu \times 10^6$ ) for the 97 glitches published in Joshi et al. (2002) and the glitch described here.

are large gaps between observations. The timing residuals of PSR J1806–2125 show small amounts of timing noise; the pre- and post-glitch residuals (Table 2) have root-mean-square values of 3.4 and 8.2 ms respectively. As the pre- and post-glitch data sets are only  $\sim 1$  year in length, these fits may under-estimate the amount of timing noise which may have been absorbed in the rotational parameters or position. In particular, the position given in Table 1 may be in error by more than the quoted formal uncertainty. Even if PSR J1806–2125 had similar timing noise properties to PSR B1951+32, which is known to exhibit extreme amounts of timing noise (Foster et al. 1994), its apparent fractional frequency change through the data would still be less than  $\sim 10^{-8}$ . This would not affect the main parameters of the glitch given in Table 2.

#### 4 DISCUSSION

Pulsar glitches seem to be divided into two sizes: most are large with fractional frequency increases of  $\sim 10^{-6}$  while the smaller events are in the range  $10^{-7}$  to  $10^{-9}$ . The event described in this letter is large — the fractional frequency increase is more than twice that of the largest previously known glitch (Figure 2). It is not possible to rule out the possibility that multiple glitches occurred during the gap of observations between MJDs 51462 and 51894. This large gap, due to an administration error, is an unfortunate feature of our data and highlights the importance of making regular timing observations of young pulsars. However, pulsars with large glitches tend to show larger intervals between glitches (Lyne et al. 2000) and no glitch occurred during the 600 days of well sampled observations at Jodrell Bank. Assuming that the integrated effect of the glitches is to reverse 1.7 per cent of the star’s slow-down (Lyne et al. 2000) then such giant-sized glitches can only occur every  $\sim 120$  years.

The mean size of pulsar glitches on a plot of the magnitude of frequency derivative versus rotational frequency is shown on Figure 3. Clearly, glitches occur predominantly in young pulsars located in the top right of the diagram. However, further trends are more difficult to identify. Region A on this diagram contains nine glitching pulsars with similar characteristic ages of  $\sim 10$  kyr and five pulsars with no history of glitching. The surface magnetic field strengths for the pulsars in this region range from  $10^{12}$  to  $10^{13}$  Gauss. Amongst 34 pulsars in an equivalent region centred on PSR J1806–2125 (region B on Figure 3), only four have been observed to glitch. PSR B2334+61, a pulsar which lies just above PSR J1806–2125 in this region, has been observed at Jodrell Bank for 15 years. Although the timing residuals



**Figure 3.** Pulsars that have glitched, shown on a plot of magnitude of frequency derivative versus rotational frequency. PSR 1806–2125 is indicated by a double circle. Pulsars that have glitched multiple times with a mean time between glitches less than 5 years are shown as solid circles. Open circles indicate pulsars that glitch less regularly. The size of the vertical lines reflects the mean size of glitches. The cross positions the anomalous X-ray pulsar 1RXS 1708–4009 which has also glitched (Kaspi, Lackey & Chakrabarty 2000). Lines of constant characteristic age are shown as dashed lines and constant magnetic field as dotted lines.

for this pulsar show large amounts of timing noise, no glitch has been observed; any large glitch would easily be observable. This pulsar could therefore glitch on a possibly similar 100 year timescale. However, PSR B1737–30 is also in this region and glitches regularly — nine small glitches over 8.5 years with a mean fractional frequency increase of  $221 \times 10^{-9}$  have been reported in Lyne et al. (2000) and Krawczyk et al. (2002). This suggests that the size of and time between glitches depends upon more than the pulsar’s position in the frequency–frequency derivative diagram.

Large glitch events are clearly very rare and will only be detected in pulsars which have been observed for many years. This suggests that many pulsars which have not been observed to glitch may do so on longer timescales. The existence of such large glitches offers new hope for attempts to observe thermal X-ray emission from the internal heat released following a glitch. Such a large event in a nearby pulsar would provide an opportunity for detecting such ther-

**Table 2.** Pre-glitch, post-glitch and glitch parameters extrapolated to MJD 51894. The root-mean-square timing residuals for each fit are given in the final column. The quoted errors in parentheses are twice the formal errors in the last quoted digit and are obtained from a least squares fit of a timing model to the TOAs.

|                  | Fit Interval<br>(MJD) | $\nu$<br>(Hz)   | $\dot{\nu}$<br>( $10^{-15}\text{s}^{-2}$ ) | $\ddot{\nu}$<br>( $10^{-24}\text{s}^{-3}$ ) | Residual<br>(ms) |
|------------------|-----------------------|-----------------|--|---|------------------|
| Pre-glitch       | 50820–51305           | 2.07556349(2)   | −505.9(8)                                  | −77(10)                                     | 3.4              |
| Post-glitch      | 51894–52257           | 2.075595904(10) | −523.0(16)                                 | +620(120)                                   | 8.2              |
| Glitch increment |                       | 0.00003241(2)   | −17(2)                                     | +697(120)                                   | –                |

mal emission and hence constrain the neutron star structure (Tang & Cheng 2001).

The amplitude of the transient seen in Figure 1c is less than 1 per cent of the step change in frequency and is consistent with results presented in Lyne et al. (2000). The amplitude could, of course, be much larger if the glitch occurred near the beginning of the gap of observations. The moderately large fractional change in frequency derivative ( $\Delta\dot{\nu} = -17 \times 10^{-15} \text{ s}^{-2}$  or  $\Delta\dot{\nu}/\dot{\nu} = 34 \times 10^{-3}$ ) suggests that the pulsar’s effective moment of inertia was reduced during the glitch by 3 per cent. This reduction is transitory; after  $\sim 300$  days,  $\dot{\nu}$  approximates its pre-glitch value.

This is the first observation of such an extreme glitch event. Although such large events must be rare, the great number of pulsars now known due to the highly successful Parkes multibeam survey increases the chance of studying such events in detail. Information obtained in these studies will provide unique constraints on theories of the internal structure of neutron stars and the mechanism which reduces a surprisingly large fraction of the effective moment of inertia of these massive cosmic fly-wheels.

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